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RESEARCH MEMORANDUM

WIND-TUNNEL INVESTIGATION OF AIR LOADS OVER A DOUBLE SLOTTED FLAP ON THE NACA 65(216)-215, a = 0.8 AIRFOIL SECTION

By

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NATIONAL ADVISORY COMMITTEE
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WIND-TUNNEL INVESTIGATION OF AIR LOADS OVER A DOUBLE SLOTTED FLAP ON THE NACA 65(216)-215, $a = 0.8$ AIRFOIL SECTION

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SUMMARY

A low-speed high Reynolds number investigation was conducted in the Langley two-dimensional low-turbulence pressure tunnel primarily to determine the air loads over a double slotted flap on the NACA 65(216)-215, $a = 0.8$ airfoil section.

The results indicate that the loads on a double slotted flap change slowly with variation of angle of attack but increase rapidly as the flap is deflected. The airfoil-flap combination and double slotted flap maximum air loads were realized at a flap deflection of 70° which appears nearly optimum for maximum section normal force. A maximum normal-force coefficient of 3.37 can be obtained by this airfoil-flap combination of which approximately 32 percent is supported by the double slotted flap.

INTRODUCTION

Up to the present time, very few high Reynolds number air-load data applicable to the structural design of double slotted flaps and their supporting and retracting mechanisms are available. For this reason an NACA 65(216)-215, $a = 0.8$ airfoil section equipped with a double slotted flap was tested in the Langley two-dimensional low-turbulence pressure tunnel to obtain air-load data on a double slotted flap. The double slotted flap was designed so that the vane remained stationary while the flap pivoted about a fixed point relative to the chord line and leading edge of the airfoil.

Air loads on the airfoil-flap combination and double slotted flap were determined at flap deflections ranging from 0° to 70°. Load distributions over the airfoil-flap combination were determined for several flap deflections to obtain an indication of the effect of the double slotted flap on the basic load distribution. The tests were conducted primarily at a Reynolds number of 6.3×10^6 with some variation in Reynolds number included to determine any possible scale effect on the air loads.

SYMBOLS AND COEFFICIENTS

c airfoil chord

c_v vane chord

c_f flap chord

q_o free-stream dynamic pressure

$m_{c/4}$ quarter-chord pitching moment per unit span of airfoil section with double slotted flap, positive when moment tends to increase angle of attack

n normal force per unit span of airfoil section with double slotted flap, positive when force is directed upward relative to the wing chord line

n_{max} maximum normal force per unit span of airfoil section with double slotted flap, positive when force is directed upward relative to the wing chord line

n_v normal force per unit span of vane alone, positive when force is directed upward relative to the vane chord line

$n_{v_{max}}$ maximum normal force per unit span of vane alone, positive when force is directed upward relative to the vane chord line

n_f normal force per unit span of flap alone, positive when force is directed upward relative to the flap chord line

$n_{f_{max}}$ maximum normal force per unit span of flap alone, positive when force is directed upward relative to the flap chord line

x_v chord force per unit span of vane alone, positive when force is directed rearward relative to the vane chord line

x_f chord force per unit span of flap alone, positive when force is directed rearward relative to the flap chord line

m_v moment per unit span of vane alone about vane reference point, positive when vane tends to rotate in direction to increase vane deflection

m_f moment per unit span of flap alone about flap reference point, positive when flap tends to rotate in direction to increase flap deflection

$c_{m_{c/4}}$ quarter-chord pitching-moment coefficient of airfoil section with double slotted flap $\left(\frac{m_{c/4}}{q_o c^2}\right)$

c_n normal-force coefficient of airfoil section with double slotted flap $\left(\frac{n}{q_o c}\right)$

$c_{n_{max}}$ maximum normal-force coefficient $\left(\frac{n_{max}}{q_o c}\right)$

c_{n_v} vane normal-force coefficient $\left(\frac{n_v}{q_o c_v}\right)$

$c_{n_{v_{max}}}$ maximum vane normal-force coefficient $\left(\frac{n_{v_{max}}}{q_o c_v}\right)$

c_{n_f} flap normal-force coefficient $\left(\frac{n_f}{q_o c_f}\right)$

$c_{n_{f_{max}}}$ maximum flap normal-force coefficient $\left(\frac{n_{f_{max}}}{q_o c_f}\right)$

c_{x_v} vane chord-force coefficient $\left(\frac{x_v}{q_o c_v}\right)$

c_{x_f} flap chord-force coefficient $\left(\frac{x_f}{q_o c_f}\right)$

c_{m_v} vane moment coefficient $\left(\frac{m_v}{q_o c_v^2}\right)$

c_{m_f} flap moment coefficient $\left(\frac{m_f}{q_o c_f^2}\right)$

p pressure difference across the chord line at any station along the chord

P normal-pressure coefficient $\left(p/q_o\right)$

α_o airfoil section angle of attack, degrees

δ_f flap deflection with respect to airfoil chord, degrees, positive when trailing edge of flap is deflected downward

R Reynolds number

MODEL AND TESTS

The model was an NACA 65(216)-215, $a = 0.8$ airfoil section equipped with a double slotted flap and had a 24-inch chord with the double slotted flap retracted. The span of the model was approximately 36 inches, and it was mounted in the tunnel so that it completely spanned the test section. The main wing section was constructed of laminated mahogany while the 0.096-chord vane and the 0.248-chord flap were made of red brass. Ordinates for the airfoil section, vane, and flap are presented in table I. The main wing section, vane, and flap were constructed with flush surface pressure orifices located, as given in table II, along the midspan for determining the air loads. The surfaces of the model were prepared for tests by sanding to produce aerodynamically smooth surfaces.

Sketches of the model and the double slotted flap configurations are shown as figures 1 and 2. When the flap was retracted at 0°, the flap chord line coincided with the wing section chord line. For flap deflections varying from 25° to 70°, the vane remained at a fixed position with the leading edge located on the wing chord line at a point 0.795 chord from the leading edge of the wing section. The flap pivoted about a point 0.893 chord from the wing leading edge and 0.065 chord below the wing chord line. The pivot point on the flap was located at 0.043 chord from the flap leading edge and 0.010 chord below the flap chord line.

Tests were conducted at flap deflections of 0°, 25°, 30°, 35°, 40°, 50°, 55°, and 70°. Air loads were determined from measurements of surface pressures over the wing section, vane, and flap primarily at a Reynolds number of 6.3×10^6. The air loads were obtained at a sufficient number of angles of attack to establish the maximum normal-force coefficient and the linear part of the section normal-force curve. Because the investigations were conducted at a Mach number of approximately 0.12, the data obtained are believed relatively free of the effects of compressibility.

The test data of the airfoil-flap combination have been corrected to free-air values by the following equations in which the primed quantities represent values measured in the tunnel:

$$c_n = 0.975\ c_n'$$

$$\alpha_o = 1.015\ \alpha_o'$$

$$q_o = 1.010\ q_o'$$

A complete discussion of these corrections is contained in referenco 1. In determining the chord forces of the vano and flap, skin friction has not been included.

RESULTS AND DISCUSSION

Section characteristics.- Section characteristics at flap deflections of 0°, 25°, 30°, 35°, 40°, 50°, 55°, and 70° for the airfoil-flap combination are presented in figure 3. The maximum normal-force coefficient obtained was 3.37 which occurred at a flap deflection of 70°. It is believed that slightly higher values may be obtained by a shift in the vane location or pivot point but the configuration investigated is believed to be very near optimum for maximum section normal force. The section quarter-chord pitching-moment coefficients due to the normal and chordwise forces of the airfoil-flap combination are also presented in figure 3 for the same range of flap deflection.

Double-slotted-flap loads.- Air loads on the vane and flap for flap deflections ranging from 25° to 70° are presented in figures 4 and 5. These curves show that, as the angle of attack is increased, the loads on the double slotted flap change slowly in comparison with the loads on the airfoil-flap combination. The air loads on the double slotted flap increase rapidly with flap deflection and in general, the maximum loads for any particular flap deflection may occur at any section normal-force value beyond 1.4. No uniform variation of these air loads could be expected due to the radical changes of air flow through the slots as the flap is deflected. The maximum chordwise forces of the vane and flap are negative, that is, the largest forces are directed forward and tend to retract the flap. Skin friction, which has not been included in these chord forces, would reduce their magnitude. The chord forces, however, should not be neglected when obtaining the resultant air load on the vane and flap.

The variation of the normal-force loads of the airfoil-flap combination, vane, and flap with flap deflection are presented for constant angles of attack of -4.1°, 0°, and 8.1° in figure 6. These

curves indicate that the normal-force loads on the double slotted flap build up as rapidly, if not more so, with flap deflection than do the normal-force loads on the airfoil-flap combination. As the angle of attack is increased from -4.1° to 8.1°, the normal force load on the vane decreases at the high flap deflections while those on the flap decrease for most flap deflections. This is probably due to separation of the flow at the trailing edges of the vane and flap which causes the double slotted flap to partly stall as the angle of attack is increased beyond a range of approximately -4.1° to 0°. The partial stall of the double slotted flap causes the slope of the section normal-force coefficient curve, at flap deflections ranging from 25° to 70°, to decrease as the angle of attack approaches the stall (fig. 3).

The maximum normal-force double-slotted-flap loads and maximum section normal-force loads for all flap deflections investigated are presented in figure 7. The maximum normal-force loads occur at a flap deflection of 70° which appears to be nearly optimum.

Scale effect.- Scale effect data on the section force characteristics are presented in figure 8. A change in Reynolds number from 2.9×10^6 to 8.9×10^6 did not affect the maximum section normal-force characteristics to any great extent. The scale effect data on the vane loads are presented in figure 9. As the Reynolds number is increased from 2.9×10^6 to 6.3×10^6, there appears an adverse scale effect on the vane normal-force characteristics between section normal-force coefficients values of about 2.0 and 3.0. As the Reynolds number was increased to 8.9×10^6, the values of the vane normal-force coefficients were approximately equal to those obtained at 2.9×10^6. While a decrease in magnitude of the moment coefficients was expected, a considerable increase occurred. This decrease in normal-force coefficient and increase in moment coefficient as the Reynolds number is increased from 2.9×10^6 to 6.3×10^6 is due primarily to changes in pressures over the upper surface. The pressures over the forward part of the vane decreased while higher pressures resulted over the rearward part causing the center of pressure to move rearward which resulted in a higher pitching moment about the vane reference point for a lower normal-force load. The scale effect data obtained on the flap load characteristics are presented in figure 10. In comparison with the scale effect data obtained on the vane (fig. 9), a smaller scale effect occurred on the flap normal and chordwise forces with practically no change occurring in the moment characteristics.

Load distributions.- Load distributions over the airfoil-flap combination for several flap deflections are presented in figure 11. A double peak-pressure region on the flap appears at a flap deflection of 55°. These peaks indicate that relatively high velocity regions exist on the flap with a lower velocity region between them. The main effect of the double slotted flap on the airfoil is its ability to change the flow around the airfoil in such a manner as to increase the

load carried by the main wing section without causing it to stall. The load distributions presented are useful for showing the change in load distribution as the flap is deflected and are applicable to the structural design of ribs as well as the double slotted flap.

CONCLUSIONS

The results of this investigation of the air loads over a double slotted flap on the NACA 65(216)-215, $a = 0.8$ airfoil section indicate that

1. The air loads on the double slotted flap change slowly with variation of angle of attack but increase rapidly as the flap is deflected.

2. The maximum air loads of the airfoil-flap combination and double slotted flap are obtained at a flap deflection of 70° which appears nearly optimum for maximum section normal force.

3. A maximum normal-force coefficient of 3.37 can be obtained by this airfoil-flap combination of which approximately 32 percent is carried by the double slotted flap.

4. The chord forces obtained at high flap deflections tend to retract the flap.

5. The main effect of the double slotted flap is that it causes the airfoil to carry a greater load without stalling.

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REFERENCE

1. Abbott, Ira H., von Doenhoff, Albert E., and Stivers, Louis S., Jr.: Summary of Airfoil Data. NACA ACR No. L5C05, 1945.

TABLE I.- WING, VANE, AND FLAP ORDINATES OF AN NACA 65(216)-215, a = 0.8 AIRFOIL SECTION EQUIPPED WITH A DOUBLE SLOTTED FLAP

[Stations and ordinates given in percent of wing chord]

Wing Section

Upper Surface		Lower Surface	
Station	Ordinate	Station	Ordinate
0	0	0	0
.391	1.180	.609	-1.064
.631	1.410	.869	-1.248
1.114	1.802	1.386	-1.556
2.340	2.560	2.660	-2.130
4.816	3.684	5.184	-2.950
7.307	4.537	7.693	-3.545
9.804	5.246	10.196	-4.034
14.812	6.381	15.188	-4.785
19.827	7.228	20.173	-5.332
24.849	7.871	25.151	-5.723
29.874	8.339	30.126	-5.993
34.902	8.650	35.098	-6.146
39.931	8.801	40.069	-6.189
44.972	8.785	45.028	-6.099
49.991	8.550	50.009	-5.856
55.019	8.088	54.981	-5.382
60.044	7.418	59.956	-4.760
65.064	6.578	64.936	-4.010
70.078	5.625	69.922	-3.209
75.086	4.603	74.914	-2.403
80.095	3.539	79.905	-1.631
85.081	2.453	84.919	-.949
90.047	1.406	89.953	-.434
95.016	.539	94.984	-.099
100.000	0	100.000	0

L.E. radius: 1.498
Slope of radius through L.E.: 0.097

Vane

Vane station	Upper surface	Lower surface
0	0	-------
.164	.558	-0.633
.328	.820	-.869
.492	1.007	-1.017
.656	1.132	-1.116
.820	1.240	-1.175
.984	1.345	-1.198
1.148	1.411	-1.207
1.312	1.476	-1.198
1.640	1.575	-1.175
2.297	1.690	-1.066
2.953	1.739	-.925
3.609	1.706	-.771
4.593	1.565	-.551
5.577	1.273	-.328
6.234	.952	-.207
6.562	.764	-.200
6.890	.541	-.246
7.218	.295	-.358
7.874	-.279	-.702
8.530	-.919	-1.194
9.186	-1.591	-1.811
9.498	-------	-2.113
9.580	-2.001	-------

Flap

Flap station	Upper surface	Lower surface
0	-1.207	-------
.017	-.926	-1.438
.082	-.695	-1.604
.124	-.561	-1.703
.186	-.462	-1.753
.310	-.231	-1.902
.621	.216	-2.101
1.241	.859	-2.215
1.862	1.373	-2.150
2.483	1.753	-2.051
3.725	2.314	-1.885
4.966	2.662	-1.718
6.208	2.793	-1.522
7.449	2.778	-1.356
8.691	2.629	-1.189
9.932	2.413	-1.058
12.415	1.885	-.777
14.898	1.388	-.529
17.381	.941	-.313
19.864	.596	-.166
22.247	.298	-.082
24.830	.050	-.050

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TABLE II.- WING, VANE, AND FLAP ORIFICE LOCATIONS OF AN NACA 65(216)-215, a = 0.8 AIRFOIL EQUIPPED WITH A DOUBLE SLOTTED FLAP

[Stations given in percent of wing chord from reference point of wing, vane, or flap]

Wing section

Upper orifice station	Lower orifice station
1.167	1.292
2.375	2.667
4.875	5.208
7.333	7.708
9.875	10.208
14.875	15.292
24.958	25.125
35.000	35.083
40.000	40.083
45.063	45.042
50.083	50.083
55.042	55.000
65.083	65.000
77.083	

Vane

Upper orifice station	Lower orifice station
1.848	0.033
4.783	3.570
6.630	5.995
7.861	7.710
9.360	

Flap

Upper orifice station	Lower orifice station
0	1.242
1.242	2.483
2.483	6.208
3.725	9.932
4.966	12.415
6.208	16.140
8.691	21.106
12.415	
16.140	
21.106	

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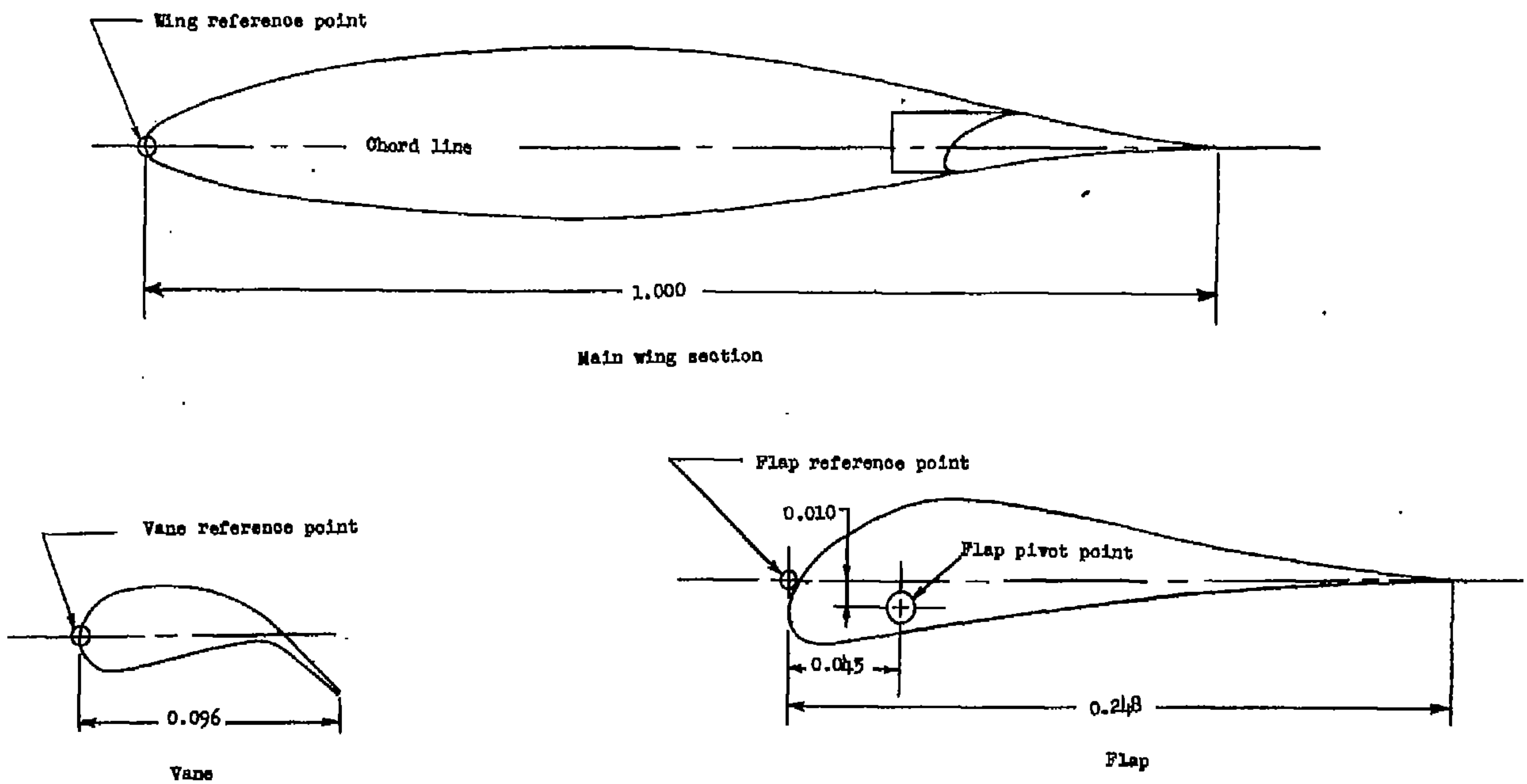

[All dimensions are given in fraction of the wing chord]

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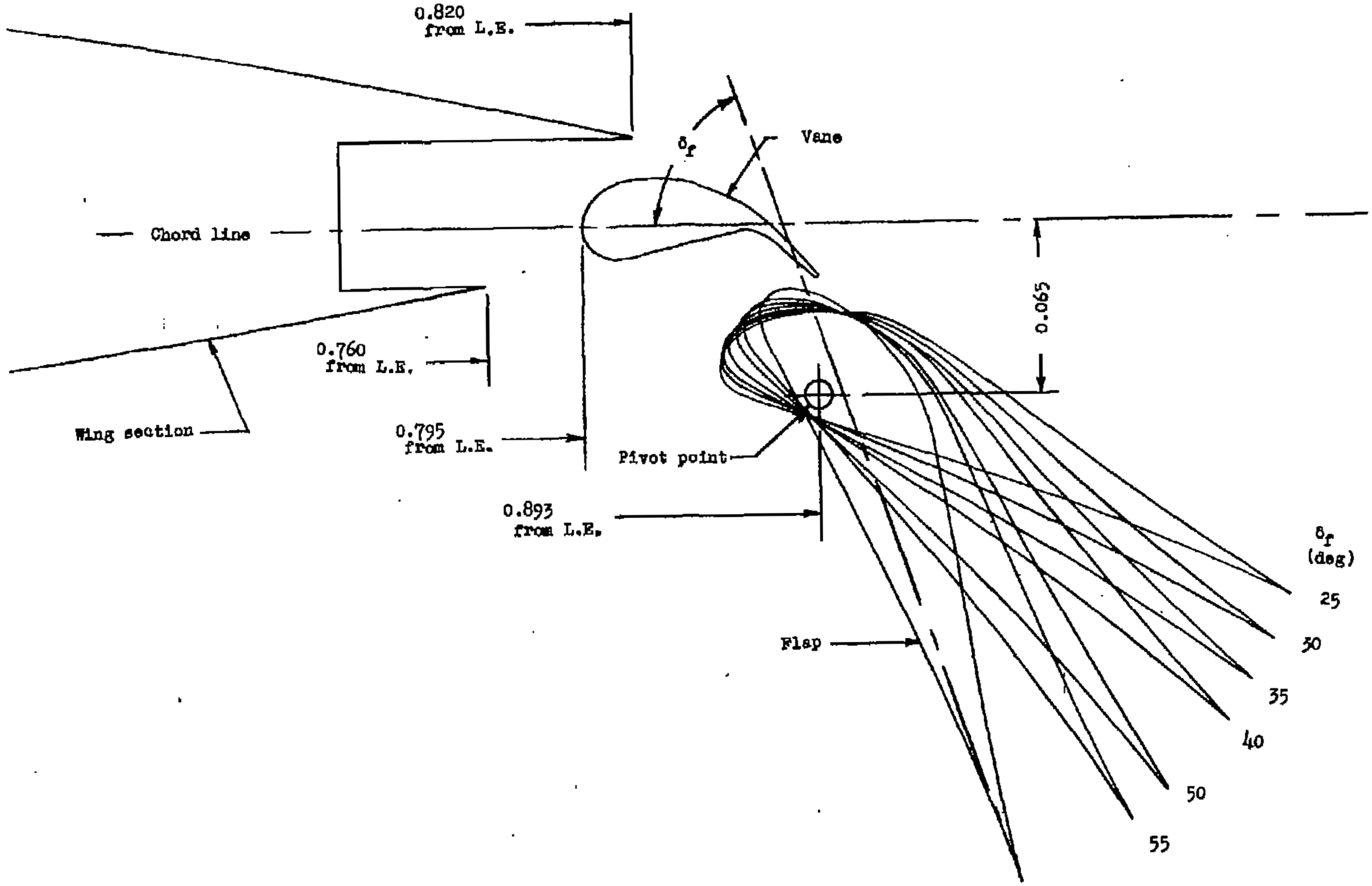
Figure 1.- Wing, vane, and flap of the NACA 65(216)-215, a = 0.8 airfoil section.



[All dimensions are given in fraction of the wing chord]

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Figure 2.- Double slotted flap configurations on an NACA 65(216)-215, a = 0.8 airfoil section.

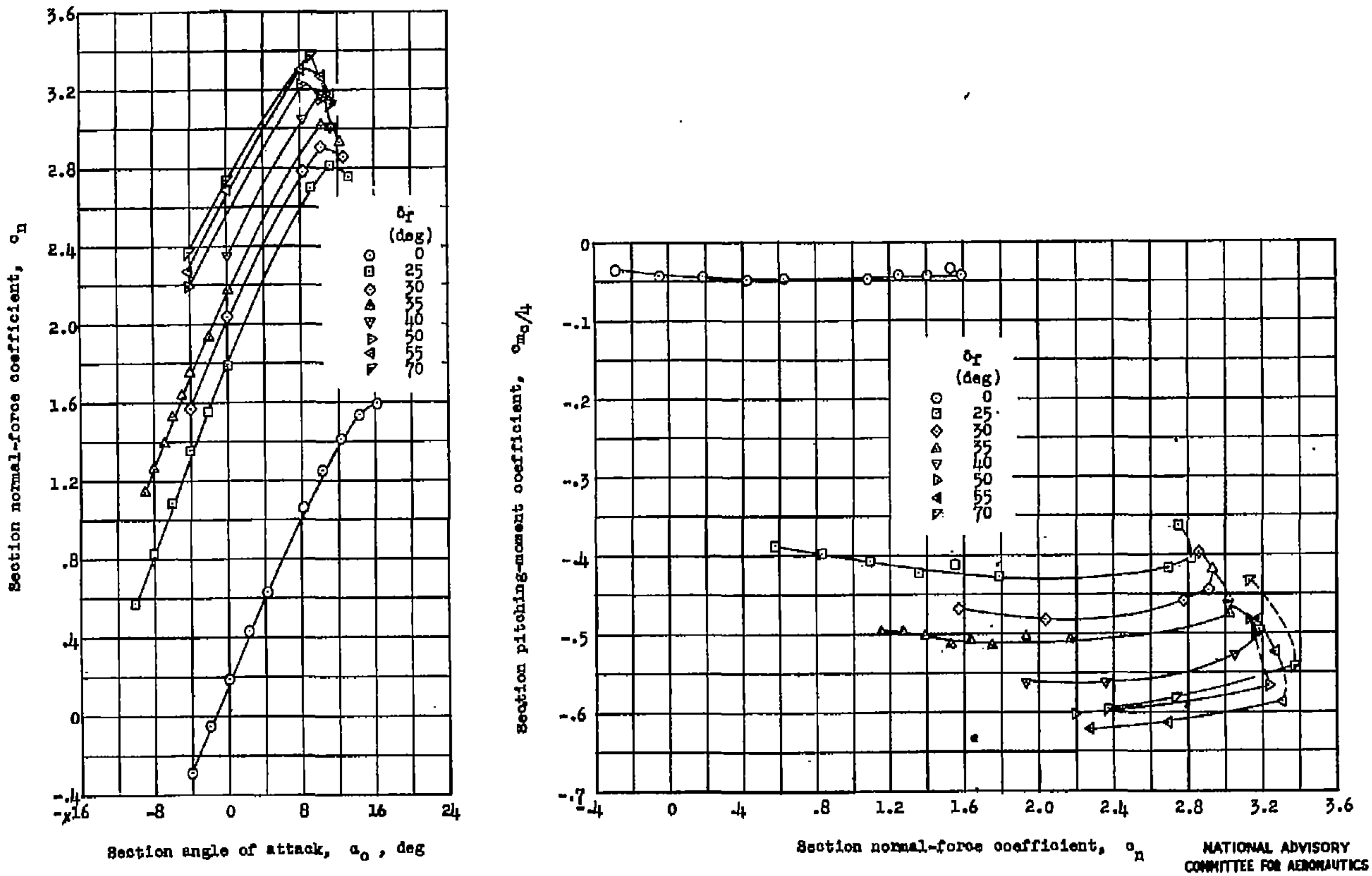

Figure 3 .- Section normal-force and pitching-moment characteristics of an NACA 65(216)-215, a = 0.8 airfoil section equipped with a double slotted flap. $R = 6.3 \times 10^6$.

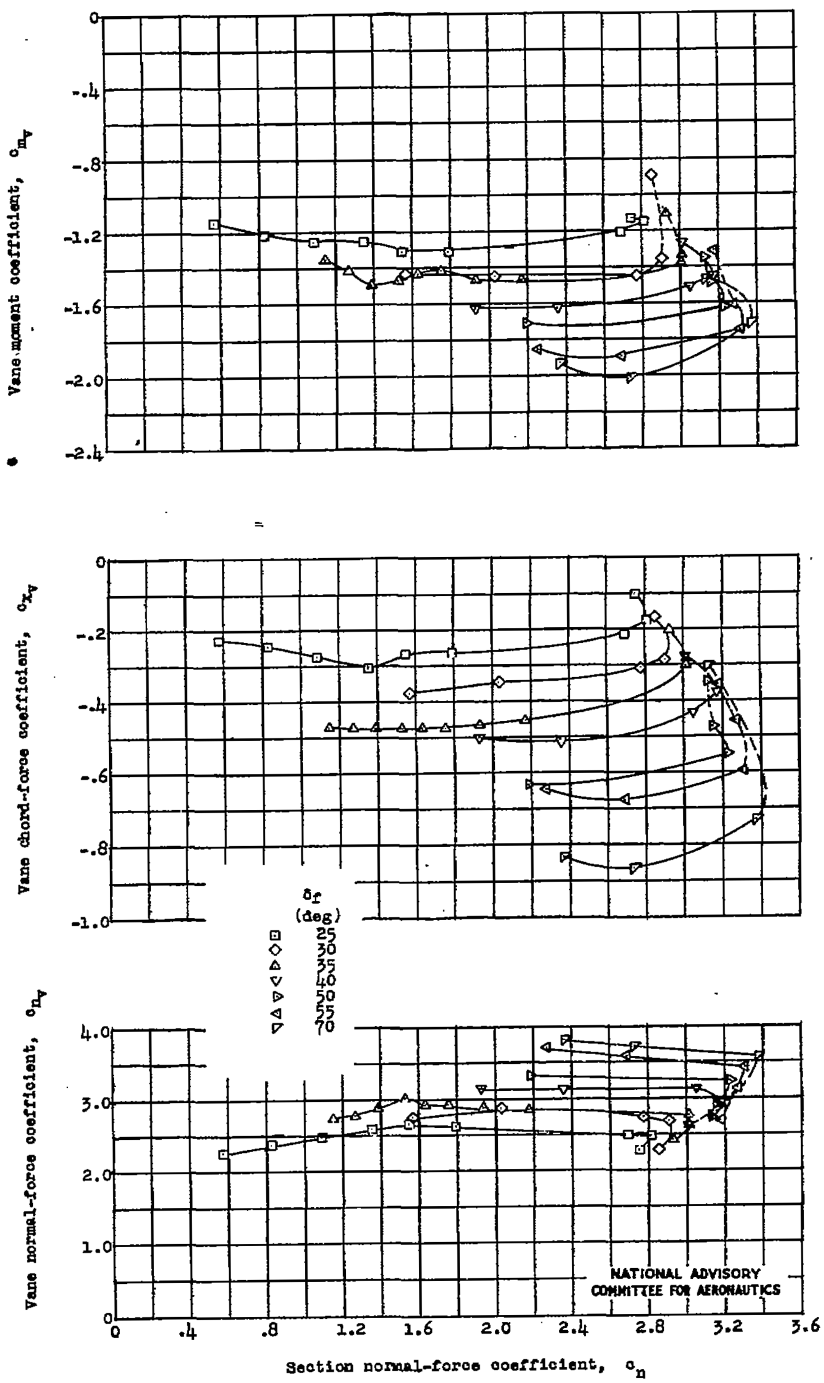

Figure 4.- Vane force characteristics of an NACA 65(216)-215, a = 0.8 airfoil section equipped with a double slotted flap. $R = 6.3 \times 10^6$.

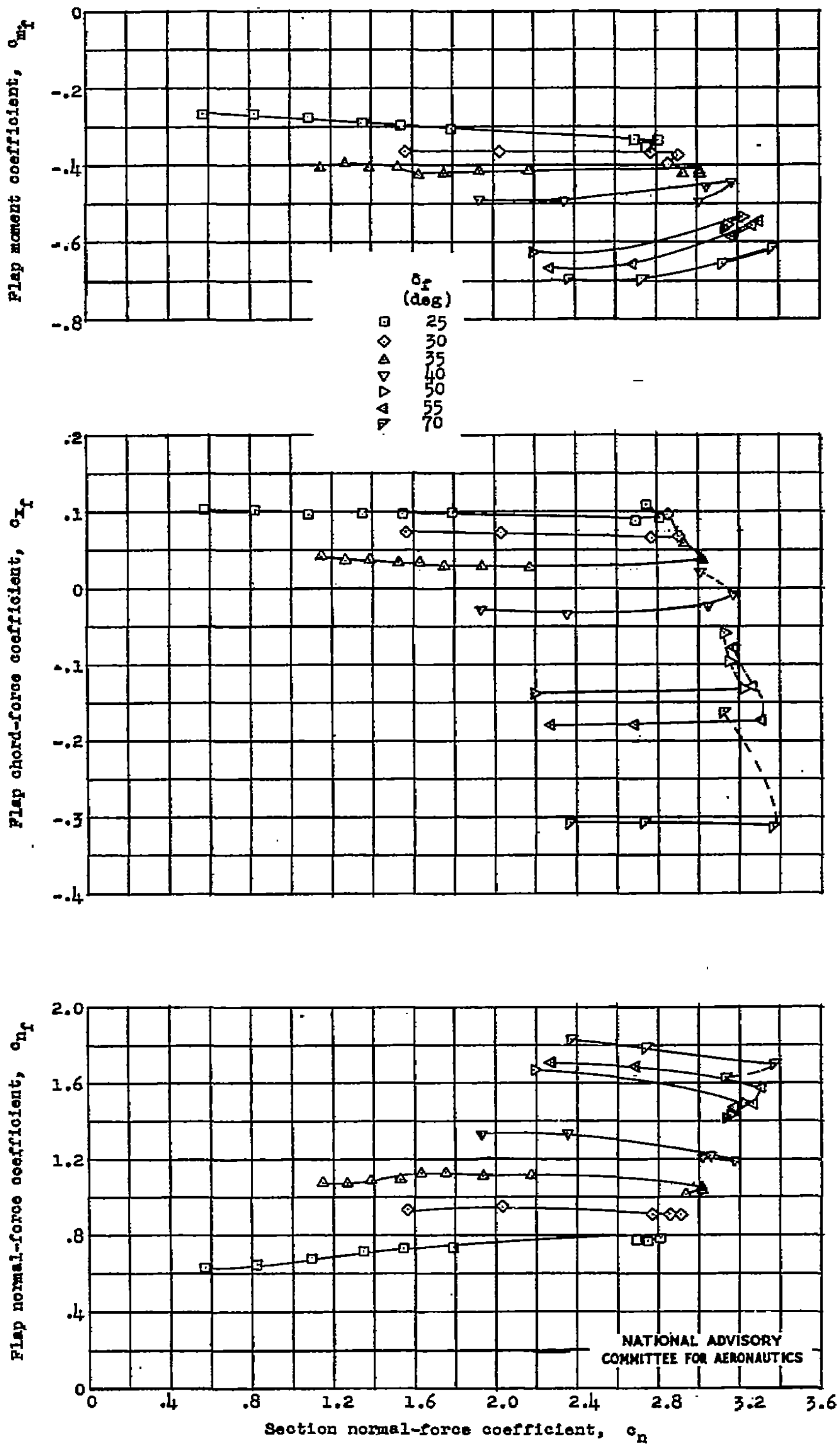

Figure 5 .- Flap force characteristics of an NACA 65(216)-215, a = 0.8 airfoil section equipped with a double slotted flap. $R = 6.3 \times 10^6$.

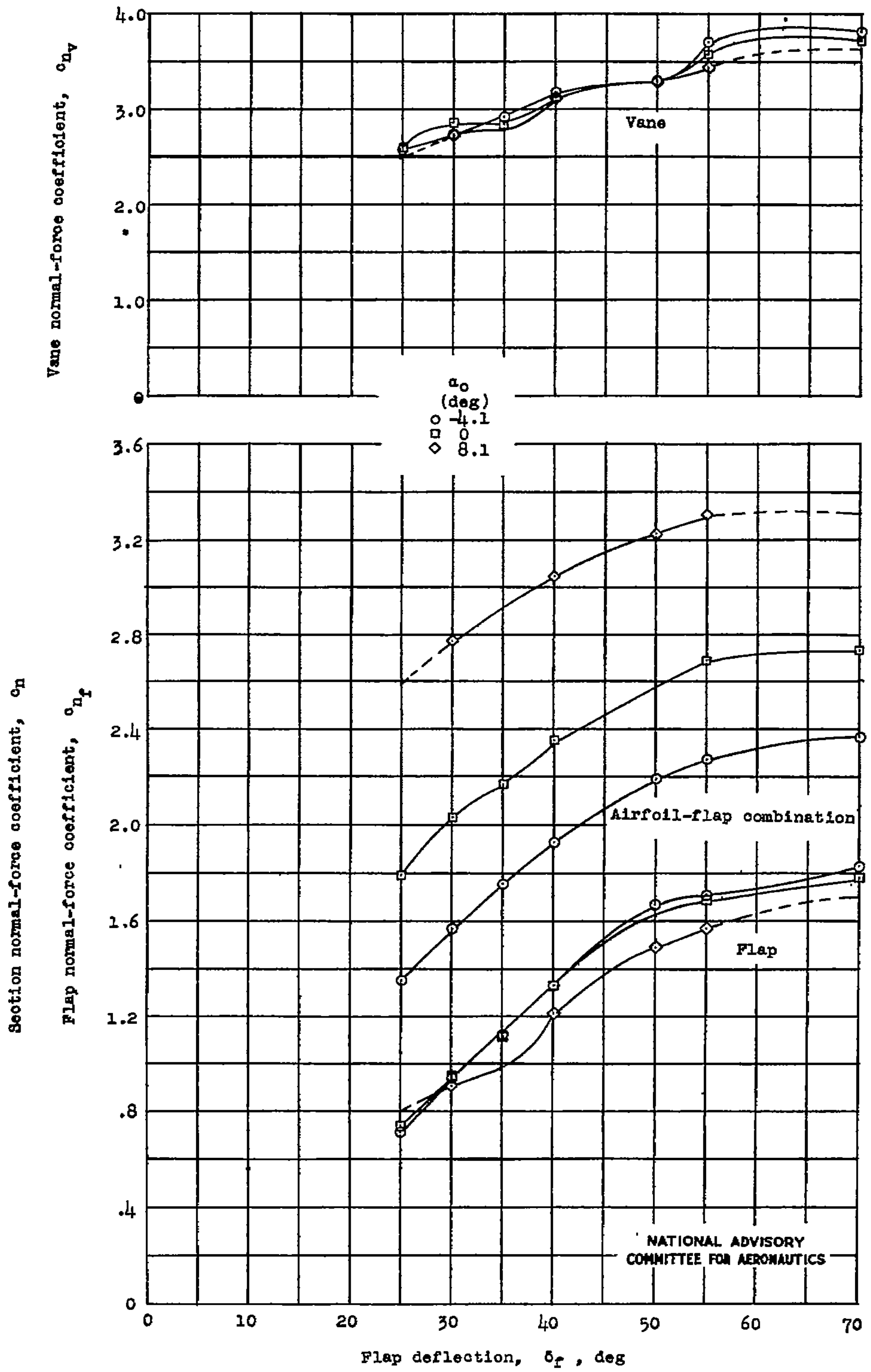

Figure 6 .- Variation of normal-force coefficients with flap deflection of an NACA 65(216)-215, a = 0.8 airfoil section equipped with a double slotted flap. $R = 6.3 \times 10^6$.

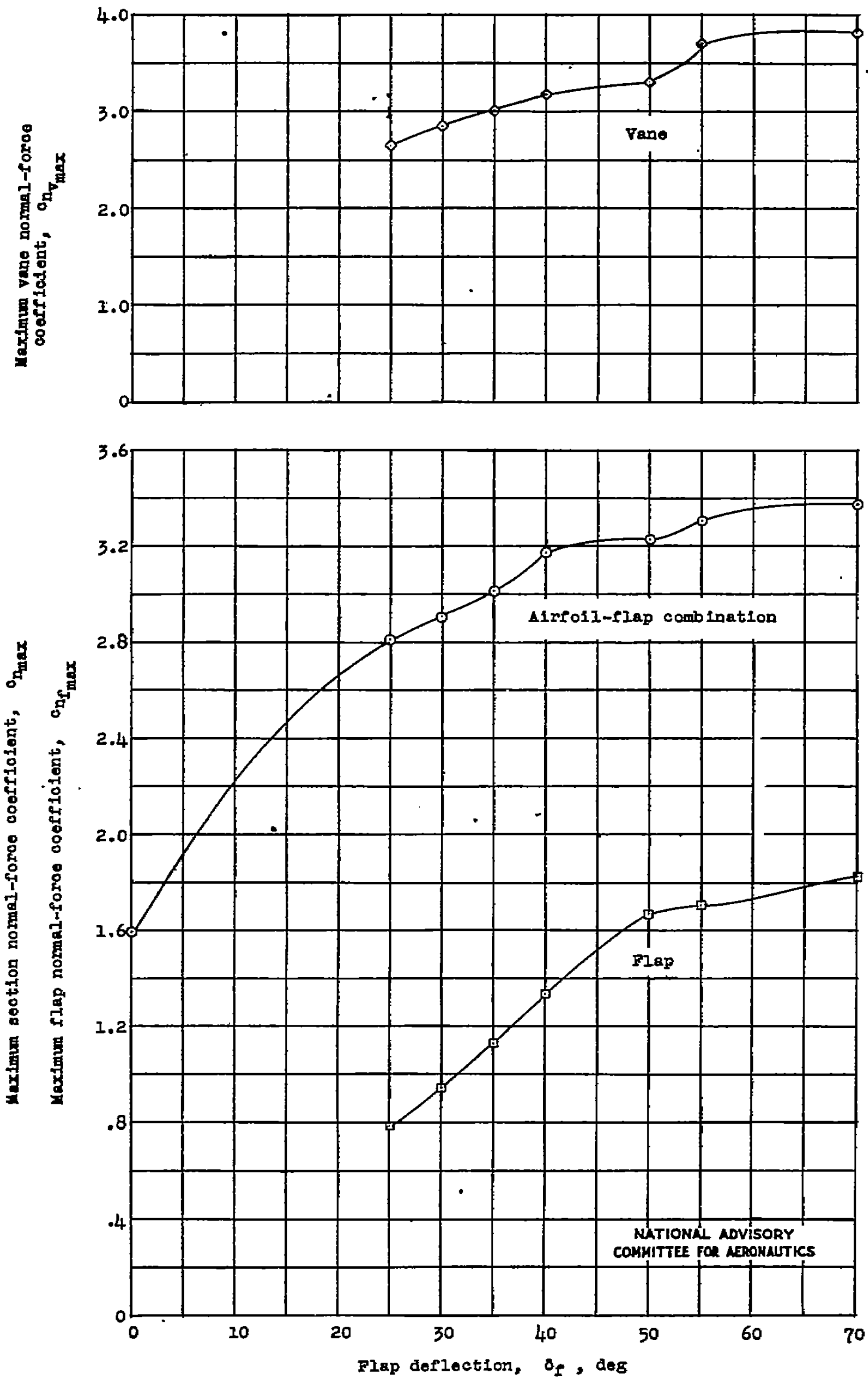

Figure 7 .- Variation of maximum normal-force coefficients with flap deflection of an NACA 65(216)-215, a = 0.8 airfoil section equipped with a double slotted flap. $R = 6.3 \times 10^6$.

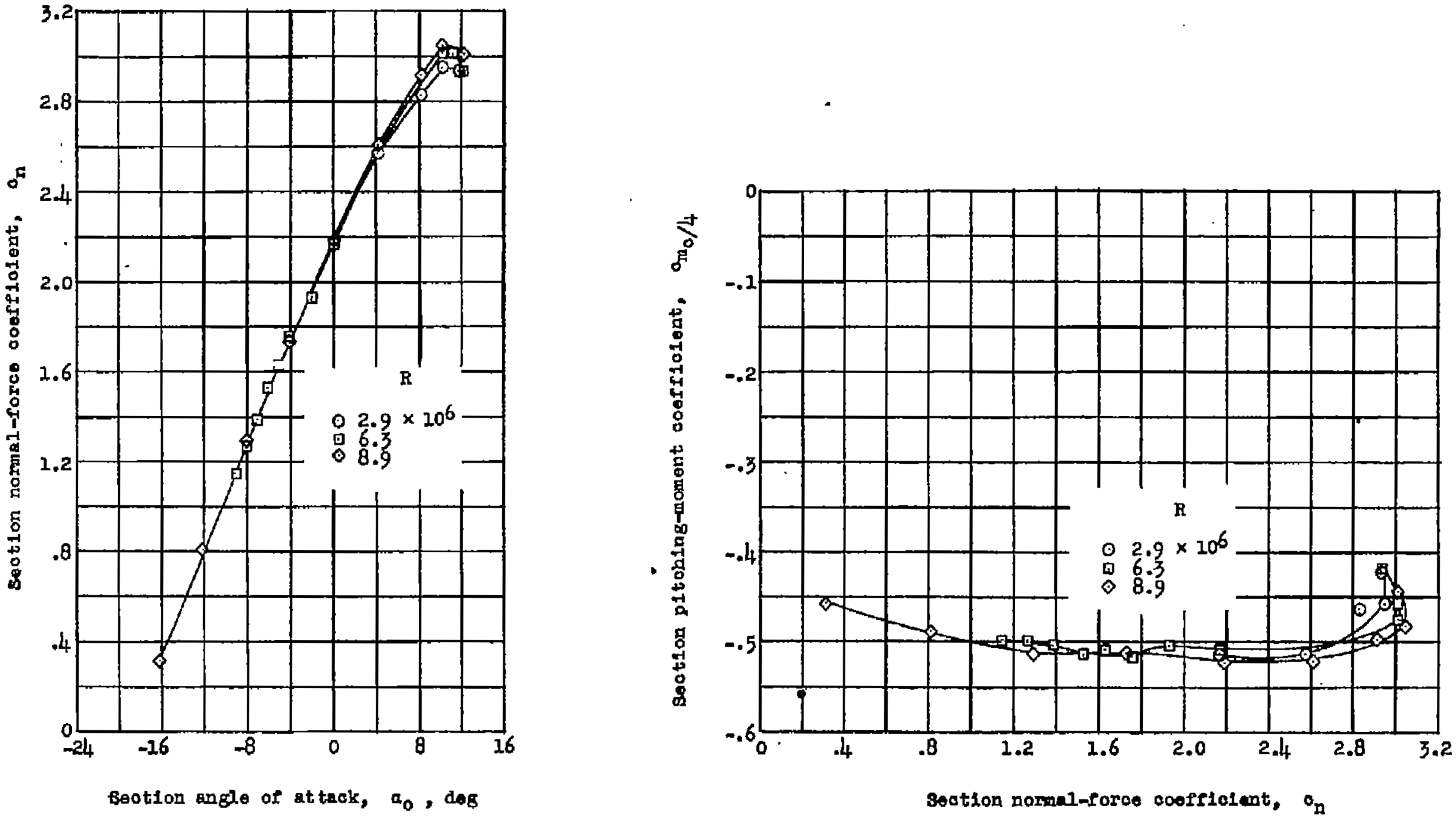

Figure 8.- Scale effect on section characteristics of the NACA 65(216)-215, a = 0.8 airfoil section equipped with a double slotted flap. $\delta_f = 35^\circ$.

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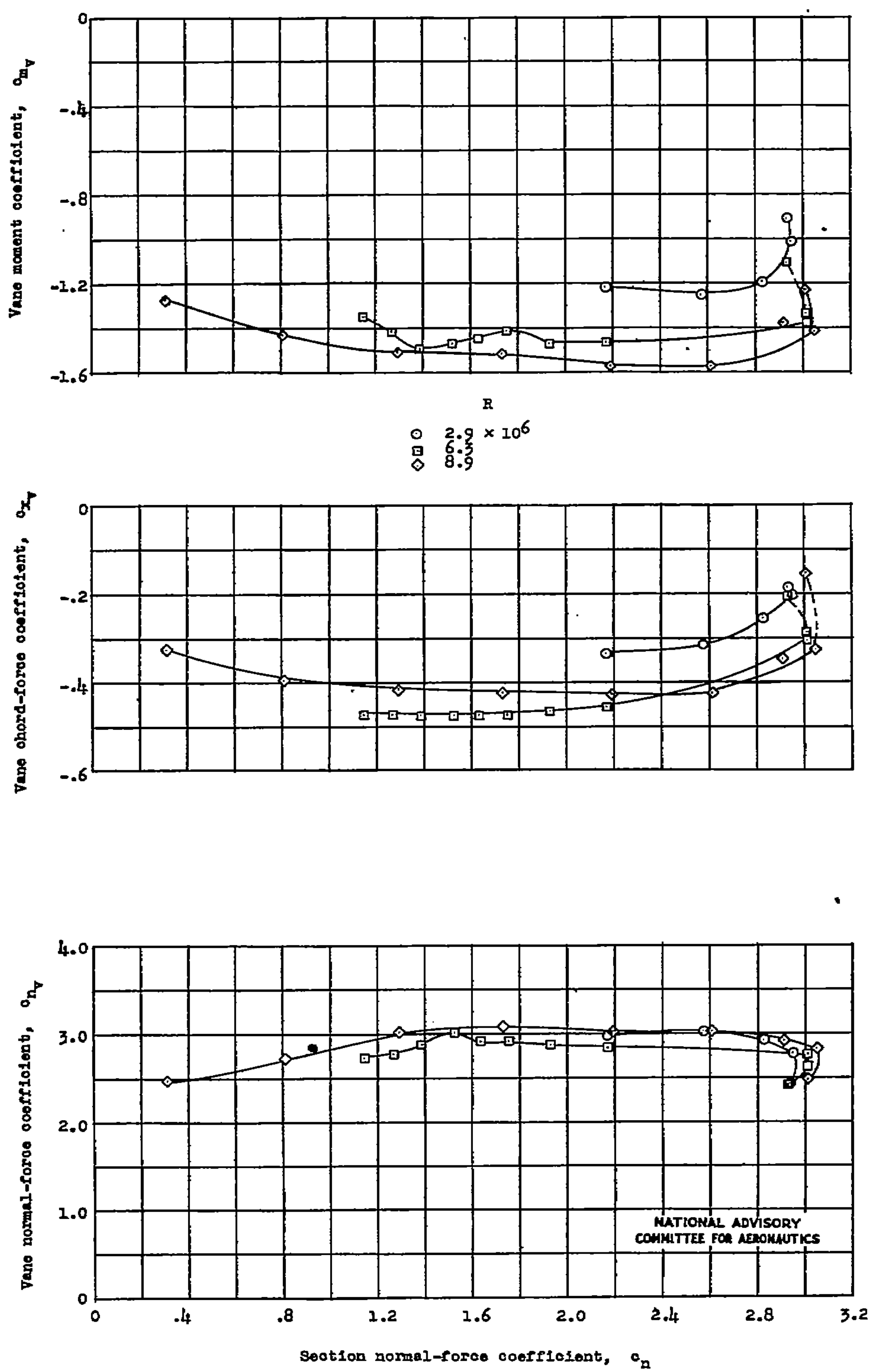

Figure 9.- Scale effect on vane characteristics of the NACA 65(216)-215, $a = 0.8$ airfoil section equipped with a double slotted flap. $\delta_f = 35^\circ$.

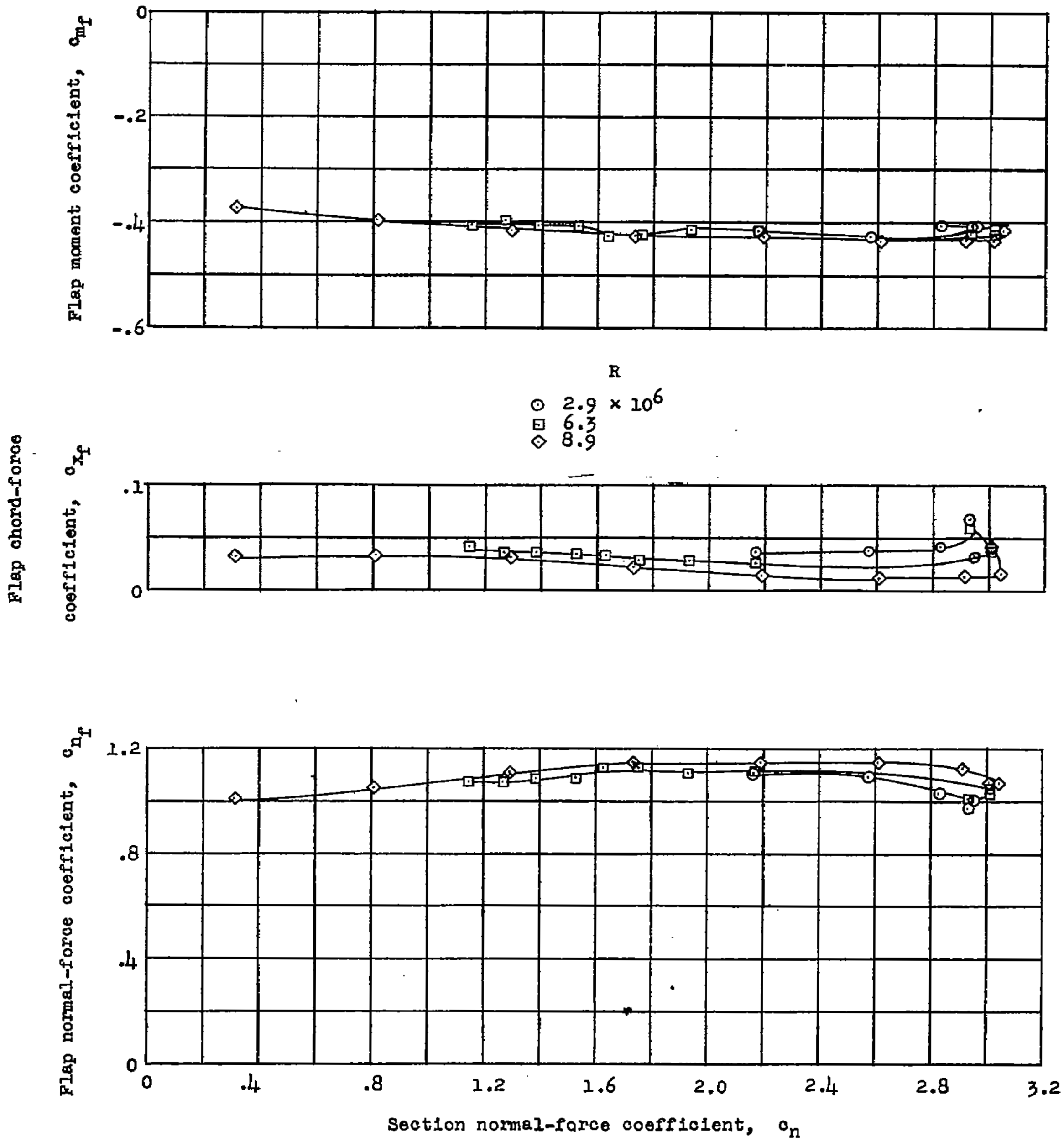

Figure 10.- Scale effect on flap characteristics of the NACA 65(216)-215, a = 0.8 airfoil section equipped with a double slotted flap. $\delta_f = 35^\circ$.

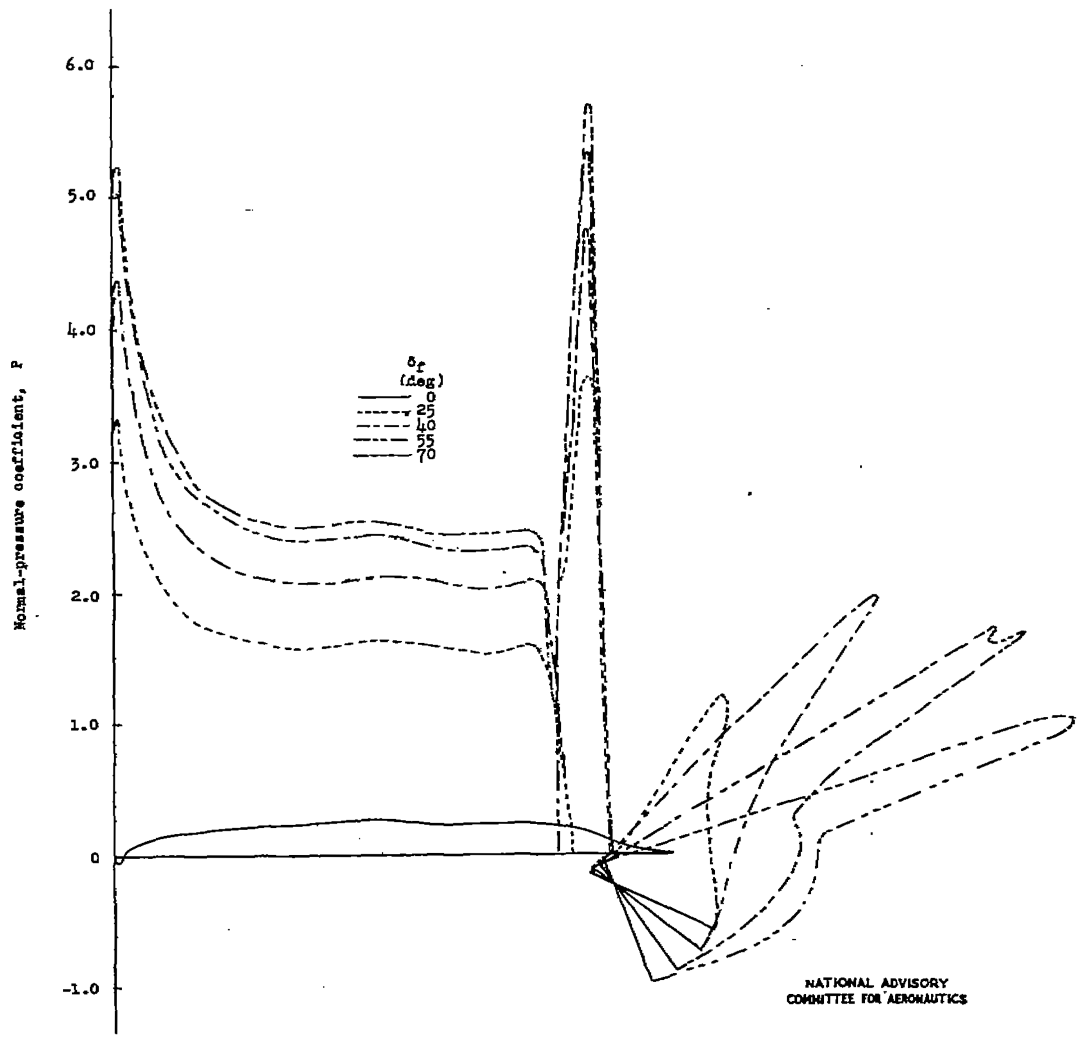

Figure 11.- Variation of load distribution with flap deflection at a constant angle of attack of 0° for the NACA 65(216)-215, a = 0.8 airfoil section equipped with a double slotted flap. $R = 6.3 \times 10^6$.